THE MEASUREMENTS OF THE ALBEDO OF A SNOW COVER

By N. N. KALITIN

Up to the present time we are in possession of a very scanty amount of data characterizing the reflective property of a land surface (bare soil, vegetative cover, water surface, snow cover), notwithstanding the great importance of this agent in thermal processes taking place in the soil and the atmosphere. This might be explained by a lack of apparatus allowing sufficiently simple and accurate measurements of the albedo of different kinds of surfaces.

Some time ago A. Ångström proposed an instrument [1] by means of which the albedo of any surface can be measured in a very simple and accurate way.

Under the term "albedo" will further be understood the amount of radiant energy reflected and expressed in per cents in respect of the direct energy.

This note is an exposition of a systematical study of the albedo of the snow-cover surface carried out in winter and spring, 1929, at the Magnetic Meteorological Observatory Sloutzk (Pavlovsk), near Leningrad.

The measurements were effected with the help of a pyranometer (A. Ångström) in connection with the loop galvanometer (C. Zeiss). Owing to the nonperiodicity and a considerable sensitivity of this galvanometer, it is especially adapted to the work conjointly with a pyranometer. The pyranometer being almost devoid of inertia and the loop galvanometer possessing a very quick receptivity, the measurements can be effected in several seconds.

For the work the pyranometer was adjusted to a special permanent installation, shown in Figure 1.

Last autumn a pillar on the top of which a brass guide tube was adjusted horizontally was sunk into the earth in an open lawn. Another brass tube, 2 meters long, was inserted into the first. On one end of this inner tube was adjusted the pyranometer so that in rotating the tube at 180° the receptive surface of the pyranometer could be placed horizontally and turned upward or downward. This placed the pyranometer above the surface of the snow cover, which remained intact during all the work. The sensitivity of the pyranometer (A. Ångström) N 29 connected to the loop galvonometer (Zeiss No.) may be determined as—, 1° of the scale of the galvanometer being equal to 0.0081 cal.

Systematical measurements of the albedo of the snow-cover surface were effected almost daily from February 16 to May 29, 1929. The snow cover having finally disappeared toward April 23, the systematical measurements effected during a whole month without the snow cover allowed us to observe the changes of the albedo accompanying the development of the vegetative cover.

Every series of measurements was formed of four readings of the galvanometer with the receptive surface turned upward and of three readings with the receptive surface turned downward. The readings were made alternately—upward, downward, upward, etc.; that supplied in the mean, five separate measurements of the albedo, the measurements of the whole series lasting four minutes.

In Table 1 is inserted a specimen of measurement of the albedo of the snow cover giving the maximum value for all the period of measurements.

[1] *A. Ångström.* A new instrument for measuring sky radiation. MONTHLY WEATHER REVIEW. 1919, No. 4.

TABLE 1.—*A sample of measurements of the albedo of a snow-cover surface March 11, 1929 (cloudiness, 7 Ci°°)*

Hours of observation		Reading of the galvanometer	Mean	Albedo	Mean of all measurements
				Per cent	
13h 46m	Upward	65.7			
	Downward	57.5	66.0	87.1	87.0 per cent.
	Upward	66.3	57.6	86.7	
	Downward	57.7	65.9	87.6	
	Upward	65.5	57.1	87.2	
	Downward	56.5	65.5	86.3	
13h 50m	Upward	65.5			

The mean deduced from five measurements determined the albedo of the snow-cover surface at the mediate moment of observations. The observations were suspended when there occurred precipitations (snow or rain) or when the radiation was rapidly changing owing to clouds suddenly covering or uncovering large portions of the sky or to a continued cover of clouds drifting with great speed. On some days it proved possible to effect not less than eight series of measurements; in some rare cases one a day.

In Table 2 are given the mean values deduced from all the series of observations. For the sake of abbreviation the hours and minutes of observations, as well as the state of cloudiness and of snow cover, have not been inserted into this table. As to the snow cover, some details regarding its state will be given further.

TABLE 2.—*Albedo surface of snow cover*

	Mean from all separate series of measurements								Mean of all measurements
Feb. 16	79.0	71.0	74.0	77.3	75.6	71.9			74.8
Feb. 17	79.2	77.8	79.3						78.8
Feb. 24	81.9								81.9
Feb. 25	79.7	81.8	85.0						82.2
Feb. 28	83.3	82.1							82.7
Mar. 2	78.4	78.7	80.5	82.1					79.9
Mar. 3	78.3	74.8	78.8	80.9					78.2
Mar. 4	83.3	83.1	84.5	84.7	82.7	81.9			83.4
Mar. 10	81.8	81.2	79.9						81.0
Mar. 11	82.6	82.2	82.0	84.4	85.5	87.0			84.0
Mar. 12	78.3								78.3
Mar. 14	72.6	72.7	70.8	71.4					71.9
Mar. 17	76.4	79.6	74.6	78.3	79.2				77.6
Mar. 18	68.4	71.2	72.6	72.8					71.2
Mar. 21	64.9	67.0							66.0
Mar. 22	66.6	66.0							66.0
Mar. 31	66.1								66.1
Mar. 24	80.3	80.8	79.9	79.8	80.4				80.2
Mar. 25	76.9	77.2	76.4	74.6	74.2				75.9
Mar. 26	70.1	68.2	71.1	71.6	71.7				70.5
Mar. 27	73.4	73.2							73.3
Mar. 28	59.4	59.6	57.9	54.8	58.8	58.5			58.2
Mar. 29	57.8	55.0	51.2	54.8					54.7
Mar. 30	53.5	55.7	56.4						55.2
Mar. 31	78.1	77.4	77.4	76.1	72.6				76.3
Apr. 1	77.4	76.4	77.1						77.0
Apr. 2	80.3	76.6	75.1	73.2					76.3
Apr. 3	79.6	75.1	77.1	80.0	82.6				78.9
Apr. 4	72.5	72.8	71.6	72.5	76.8	79.8			74.3
Apr. 5	74.2	70.7	71.3	67.7	69.1	66.7			70.0
Apr. 6	64.9	68.9	70.3	68.0	70.9				68.6
Apr. 7	71.5	67.5							69 5
Apr. 8	66.4	66.8	69.5	68.7	72.5	74.4			69.7
Apr. 9	70.7	59.3							65.0
Apr. 10	61.3	63.0	62.1	58.4	58.5				60.7
Apr. 11	60.8	56.7							58.8
Apr. 12	57.4	53.9	53.2						54.8
Apr. 13	47.9	60.6							54.2
Apr. 14	45.4	46.1	46.3	48.0					46.4
Apr. 15	75.3	69.0							72.2

TABLE 2.—*Albedo surface of snow cover*—Continued

	Mean from all separate series of measurements								Mean of all measurements
Apr. 16	74.3	75.4	68.2						72.6
Apr. 17	79.2	71.5	71.8	70.2	66.6	63.2	60.6	58.6	67.7
Apr. 19	28.3	24.9	21.5						24.9
Apr. 21	49.6	40.6							45.1
Apr. 23	18.4	23.9							21.2
Apr. 28	20.7	18.0	18.5						19.1
Apr. 29	17.9	16.5	18.5						17.6
May 2	18.0	20.7	22.0	22.1	21.7				20.9
May 4	18.6	17.1	18.8	19.4					18.5
May 5	19.2	(14.9)	(14.0)						19.2
May 6	20.3	22.2	21.7	19.0					20.8
May 8	21.3	21.4	22.2	24.7					20.8
May 9	19.7	22.9	21.5	16.3					20.1
May 11	(17.8)	20.5	20.1	19.6					20.0
May 12	22.3	20.0	17.8	17.3					19.3
May 13	22.5	23.8	18.1						21.5
May 16	22.9	20.9							21.9
May 18	21.0	19.8	20.6						20.5
May 19	22.0	18.2	19.9	21.0	24.3				21.1
May 20	21.1	23.2	22.5						22.3
May 22	22.9	21.4	23.1	20.1					21.9
May 23	24.3	22.9	20.6						22.6
May 26	22.9	23.4	22.4						22.6
May 29	25.3	26.9	22.5	(33.2)	25.7	(37.2)			24.9

The last column of Table 2, giving the mean albedo for each day when the measurements were effected, has been graphically presented in Figure 2.

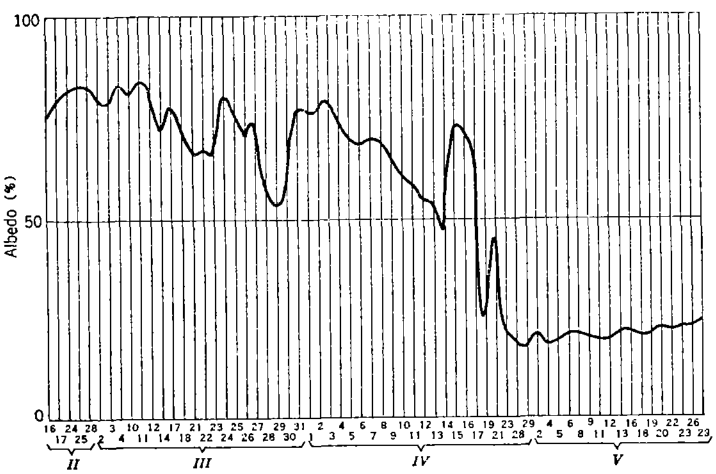

FIGURE 2.—Curve of the change of the albedo of a snow cover within the period April 16–23, inclusive, and of soil covered with grass, May 24–29, inclusive

From Figure 2 it becomes clear that in the presence of the snow cover the albedo will show rapid and considerable changes. The reflective capacity of the snow cover depends upon its form and state. The newly fallen mellow snow possesses a more important albedo than the snow of some days' old;[1] the winds and thaws that increase the density of the surface of the snow cover decrease the value of its albedo.

The fluctuations of the rate of the albedo seen so distinctly in Table 2 may be explained either by the recent fall of snow (the albedo keeping to its high rate or increasing) or by thaws (decreasing albedo), when the thawing of the upper surface of the snow cover considerably reduces its reflective power.

In order to explain the ups and downs of the curve in Figure 2, it is necessary to know the conditions which could have affected the albedo, particularly the moments of snowfall and thaw. (Table 3.)

[1] *A. Ångström.* The albedo of various surfaces of ground. Geografiska Annaler, 1925. No. 4.

TABLE 3.—*The conditions controlling the state of the snow cover*

Days with snowfall:
- February 19, 22, 23, 27.
- March 1, 2, 3, 4, 5, 8, 9, 10, 12, 13, 15, 16, 17, 18, 24, 26, 28, 29, 31.
- April 1, 12, 14, 15, 18, 21, 22, 24, 27, 29.

Days when the diurnal mean of air temperature was above 0°:
- February: None.
- March 12, 13, 14, 20, 21, 22, 23, 27, 28, 29.
- April 12, 13, 14, 18, 19, 20, 23, 25, 26, 27, 28, 29, 30.

The sinuosities of the curve may be explained by means of their confrontation with the values of Table 3.

Thus up to March 12 there occurred no thaws and the albedo remained almost at the same level; in the meantime occurred frequent snowfalls and the fresh fallen snow maintained the reflective power of the snow cover almost at one level. The small decrease of the albedo on March 3 may be explained by the fact that the temperature of the air rose above 0° and apparently somewhat affected the condition of the snow cover.

Three days of thaws (March 12, 13, and 14) reduced the albedo from 84 to 72 per cent the snowfalls on the 15th, 16th, and 17th raised it again to 78 per cent. The next four days with thaws (March 20, 21, 22, and 23) decreased the albedo anew to 66 per cent; the snowfall of March 24 increased it again to 80 per cent, etc.

The fall of the albedo down to 55 per cent on the 29th and 30th may be explained by a considerable thaw having taken place an the 27th, 28th and 29th.

Very interesting is the continued decrease of the albedo from April 3 (79 per cent) to April 14 (46 per cent), which may be explained by an absence of snowfall up to the 12th, owing to which the snow cover became denser and its reflective property was reduced; on the 12th there was a snowfall accompanied by a thaw which reduced the albedo down to 46 per cent. It has to be noted, though, that within the period April 3 to 12 the maximum temperature of the air attained more than once a value exceeding zero, which ought also to have increased the thaw of the surface of the snow cover, decreasing its reflective power. The considerable rise of the albedo on April 15 and 16 (79 per cent) has to be explained by the fresh fallen snow and the air temperature below 0°.

Places of melting of the snow cover within the region of the installation of the pyranometer commenced to appear since April 18. Till then the snow cover was continuous but rather soiled; some trees growing not very far from the installation, the thaw brought to the surface a certain amount of pine-tree needles and other incrustments.

The maximum value observed during the whole period amounted to 87 per cent having occurred on March 11 at 13 h. 48 m., with cloudiness of 7 Ci. This day the snow cover was dazzling, fresh soft snow having fallen on the eve, and its surface was sparkling the last words of this day's log in the observer's notebook being: "Eyes aching after observations," which also indicates an exclusive reflective power of the snow cover on that day.

The maximum values previously obtained having been: C. Dorno, 89 per cent; Abbot and Aldrich, 70 per cent; A. Ångström, 81 per cent.

The snow cover disappeared on April 23, and after that the measurements of the albedo were carried on during a little more than a month with the help of the same installation and at the same place. The mean albedo of the vegetative cover proved to be equal to 20.8 per cent and displayed a small though systematical increase in accordance with the development of the vegetative cover. Immediately after the snow cover disappeared and bared the last year dry turf, very soiled by incrustements left by the snow, the albedo was 19 per cent, 18 per cent. Further, the area of new green grass augmenting from day to day and having attained with respect to the dry grass from 80 to 90 per cent, the albedo attained 23 per cent.

It was mentioned by A. Ångström that the wet grass gives a greater value of the albedo than the dry—e. g., for dry grass he obtained 32 per cent, whereas for wet grass (after a rainfall) but 22 per cent.

Among the series of observations I have had at my disposal some were made at once without rain and with rain. The picture obtained is the following: When the sun shines and the grass is wet the obtained albedo will be greater than with dry grass; if, on the contrary, the albedo of wet grass is measured, the sky being overcast, a smaller value is obtained for wet grass than for dry turf; this is clearly seen from Table 4.

TABLE 4.—*The albedo of a wet grass cover (under rain)*

Time of observations	Albedo	Conditions of observations
		May 29, 1929
h. m.	*Per cent*	
14 27	22.5	Dry grass, no sun.
14 50	33.2	Immediately after rain, sun.
14 54	25.7	No sun.
14 59	37.2	Sun.
		May 5, 1929
9 20	19.2	No sun.
10 42	14.9	After rain.
16 40	14.0	Do.

It may be that in case of wet grass and the presence of shining sun the value of the albedo is greater owing to the crystalline reflection of sun rays. However, the observations being scarce nothing definite can be said in this respect.

AT WHAT TEMPERATURE DOES FROST OCCUR?

By W. J. HUMPHREYS

This is a familiar question most of us have answered many times, usually, perhaps, by saying that frost, in the sense of fine, feathery ice crystals, begins to form as soon as the temperature of the frosted object and the air in contact with it falls to 32° F., the well-known freezing point of pure water. We often, and properly, stress the fact that on still clear nights, the times when temperature inversions are pronounced, frost can occur on grass and other exposed surface objects, while the temperature of the free air only a few feet above the ground is several degress higher than this critical value at which, with loss of heat, water turns to ice, and, with gain of heat, ice turns to water.

That is as far into details as we usually go in answering this question, but really it is not far enough, for it omits one vitally important factor—the state of the humidity. Hoarfrost, a deposit of ice directly from the air, can not form until saturation is attained—that is, not until the temperature has fallen to the dew point, no matter how low that may be. We might, therefore, answer the question "At what temperature does frost occur?" by saying "Any temperature at or below the dew point of the air at the place of occurrence up to but not above 32° F."

The term "frost," however, has several meanings besides that given above. One of the commonest of these is "freeze," used especially in connection with injury to vegetation incident to the freezing of saps and juices. Frost in this sense, the freezing and consequent injury of vegetation, can not occur at temperatures above 32° F., since most saps are nearly all water. Neither can it occur until the temperature has fallen, certainly a little, and in some cases very much, below this point, as determined by the kind of plant and degree of concentration or dilution of the sugar and other freeze-resistant substances always present in plant liquids. But many vegetables and fruits do freeze at temperatures very little below 32° F. Also, in the spring and fall of the year, the seasons when vegetation is injured by freezing, the dew point usually is above 32° F. Hence, when vegetation is injured by freezing it is quite likely also to be covered by hoarfrost, and when covered by hoarfrost it is apt to be injured by freezing. It happens, therefore, that throughout the growing season, or from early spring to late fall, we associate the occurrence of hoarfrost with injury to vegetation, and the absence of hoarfrost with lack of injury, although, as explained, either can occur without any trace of the other.